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Advancing research on alien species and biological invasions

Defining invasive species and demonstrating impacts of biological invasions: a scientometric analysis of studies on invasive alien plants in Brazil over the past 20 years

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Abstract

Despite biological invasions being widely recognised as an important driver of environmental change, lack of consensus regarding the definition of invasive alien species (IAS) and vagueness around the demonstration of their impacts limits knowledge and research in this field. In this study, a scientometric approach was used to analyse academic documents published between 2002 and 2021 in three databases with reference to invasive alien plants in Brazil. Despite the growing body of scientific literature in the area, only 10% of the publications provided some definition of invasive species. Of the 398 publications analysed, 23.6% found some type of damage caused by the invader and, of these, only 5% addressed economic or social damage. Only 17% of the publications proposed a method for controlling and/or mitigating biological invasions. The absence of clear terminology and the lack of focus on impacts limits understanding of IAS of plants in Brazil. Based on the present findings, future studies on IAS of plants should move towards a consensus on the definition of biological invasion, as well as understand the impact caused by these species. In addition, it is recommended that further scientometric studies should guide future efforts to support objective measures for management and decision-making.

Keywords

biodiversity, impact, invasive alien species, management

Introduction

The fundamental property associated with biological invasions is the capacity of some invasive alien species (IAS) to expand and become established outside their native range (Richardson et al. 2000; Valéry et al. 2008). However, there are other important properties of biological invasions that are associated with the term 'impact' (Mack et al. 2000; Simberloff et al. 2005; Pyšek et al. 2012). This is because IAS can have detrimental effects not only on ecosystem function and services and on human well-being (Simberloff and Rejmánek 2011; Paini et al. 2016; Costa et al. 2019; Martinez-Cillero et al. 2019), but also on the economies of the invaded areas (Diagne et al. 2020; Zenni et al. 2021). However, despite wide (and implicit) acceptance in literature, controversy remains over the association between IAS and their negative impacts (Ricciardi and Ryan 2018; Sagoff 2018). Indeed, some studies have recently questioned this tenet suggesting that several factors, including lack of empirical evidence, set-up of poorly-executed experiments and over-emphasis of isolated cases, may bias proper understanding of the impacts of biological invasions (Davis and Chew 2017; Sagoff 2020). Additionally, other studies have questioned the science behind biological invasions and provided scientific evidence in support of this contention (Ricciardi and Ryan 2017; Boltovskoy et al. 2018). Furthermore, the absence of terminological consensus is another factor that has resulted in questioning the impacts of biological invasions (Simberloff 2012).

One of the key definitions of biological invasions was presented by Richardson et al. (2000), who introduced the concepts of introduction of IAS to the recipient area and their subsequent establishment by reproduction and expansion. However, the same authors emphasised that the definition of biological invasion should not be applied to species that cause environmental or economic impacts, but should be based exclusively on ecological and biogeographic criteria (Richardson et al. 2011). In contrast, Richardson and Pyšek (2012) stated that the most prominent invasive plant species were those that reached the highest abundance and had substantial impacts, thereby resulting in high costs to society. More recently, Pyšek et al. (2020) reiterated their definition of biological invasion (i.e. introduction, establishment and dispersion of an alien species), but also suggested that several negative impacts are associated with biological invasions. The same authors added that, according to the International Union for Conservation of Nature, only those alien species that have negative impacts should be classified as invasive. On the other hand, most studies that have either directly or indirectly addressed the topic of biological invasions have not presented a clear definition of 'invasiveness' and many of them have cited previously-published studies for evidence of the invasiveness of the species under study (Pereyra 2016).

The presence of IAS of plants in natural areas has been reported from different regions of the world and, in many cases, the consequences of biological invasions have been devastating (Justo et al. 2019). Ornamental use is recognised as the main route for the introduction of alien and potentially invasive plants to new regions (Hulme et al. 2017; Mayer et al. 2017). In recent years, the mechanisms behind the invasiveness of plant species in the recipient environment have been widely addressed by studies on

plant invasions (Fridley 2010; Van Kleunen et al. 2010; Wang et al. 2020). However, there are still several gaps in knowledge about the status of invasive plant establishment in natural areas (Hulme 2018), their impacts (Foxcroft et al. 2019) and related measures for control (Weidlich et al. 2020) and these gaps are even more evident in tropical biomes (Ackerman et al. 2017; Pinto et al. 2020; Xavier et al. 2021).

Using a scientometric approach (Parra et al. 2019), academic articles published in the last 20 years were analysed in this study to understand the main trends and gaps in research on IAS of plants in Brazil. The specific objectives were to: (i) analyse the main methodologies used in the field of biological invasions; (ii) evaluate whether there is a clear and objective definition of IAS; (iii) identify the type of impact caused by IAS; and (iv) investigate methods for management and/or control of biological invasions.

Methods

Scientometrics is a new branch of science that measures and quantifies scientific progress via bibliometric indicators (Parra et al. 2019). Scientometric analysis seeks to observe trends and patterns in scientific production with predictive, prognostic and/or strategic approaches (Ivancheva 2008; Rizzi et al. 2014; Mills and Rahal 2019; Xie et al. 2020). In the context of biological invasions, this represents an important tool in the analysis of conservation issues in mega-diverse natural areas such as Brazilian biomes (Frehse et al. 2016). Scientometric studies play a leading role in surveying the state of the art of scientific literature (Santos et al. 2021), developing explanatory ecological models (Barbosa et al. 2012), forecasting the impacts of invasions in poorly-studied biomes (Pinto et al. 2020) and optimising resources and directing new research (Fonseca et al. 2021).

Following a scientometric approach, a survey of scientific literature was conducted in this study according to the PRISMA statement (Moher et al. 2009) by using two global databases and one regional database that have accessible online platforms, namely: Web of Science (WoS: www.webofknowledge.com), Scopus (www.scopus.com) and SciELO (Scientific Electronic Library Online: https://www.scielo.br/). In each database, search criteria were applied to all available fields (i.e. Title, Abstract, Keywords and other fields depending on the database) and only academic articles (hereafter, 'publications') published in the last 20 years (i.e. 2002–2021) were selected. The combinations of terms used to search the databases are shown in Table 1.

Both English and Portuguese terms were used in order to retrieve more results. The base of the words was retained and "*" was used as a wildcard to expand the search (Table 1). All collected references were compared to check for redundancies between the results of the three databases. After removing duplicate references, all remaining publications were evaluated using the following three inclusion criteria:

- Study carried out in Brazil;
- Study addressing invasive alien plants;
- Study not addressing agribusiness and/or monoculture.

Table 1. Combination of terms used to retrieve publications from the Web of Science, Scopus and SciELO online databases.

Topic	Term	Combination
Biological terminology	Biological invasion Weed Exotic Non-native Non-indigenous Vegetable/Plant	("Bio*invasion*", "Invader*", "Daninha", "Exotic*", "Alien", "Non-native", "Não nativa", "Non-indigenous", and "Weed") AND (Impact*, Ecosystemic*, OR Economic*, OR Socio*) AND (Plant OR Vegetal) AND (Brasil OR Brazil)
Impact caused	Ecosystem Economic Social Impact	
Location	Brazil	

The title and abstract of each publication were then evaluated and publications were divided into three groups:

1. Within the scope of the present study, i.e. whose title and/or abstract met the inclusion criteria;
2. Potentially within the scope of the present study, i.e. whose title and abstract partially met the inclusion criteria;
3. Not within the scope of the present study, i.e. whose title and abstract did not meet any of the inclusion criteria.

The body of the text was reviewed to explore the adequacy of the inclusion criteria for publications that were potentially within the scope of the present study (Group 2). As a result, all publications in Group 2 were reclassified (hence, redistributed) between Groups 1 or 3, as applicable. Publications in Group 3 were then excluded from the database and those in Group 1 were categorised according to the attributes listed in Table 2. In this step, the abstract of each publication was analysed. If the attribute information in the abstract was insufficient, then the entire publication was analysed.

Results

In total, 7,587 publications were retrieved from the three database searches. After applying the inclusion criteria, 578 publications were selected of which 348 were from Group 1 and 230 from Group 2. After reclassifying the publications in Group 2, 398 publications were obtained (i.e. final sample size), which were used in the scientometric analysis.

A growth trend was observed in the number of publications from 2002 to 2021. In 2002, there was only one publication, whereas there were 35 in 2021

Table 2. Scientometric attributes used in the data collection.

Attribute	Meaning	Category
Year	Publication date	2002–2021
Definition	Referenced definition of invasive alien species (IAS)	1. Definition not provide 2. Definition provided
Category	Main methodology used	1. List of species: field or bibliographic survey of alien species that occur in an area. 2. Ecology: study explored the biological attributes of the alien species and/or their relationship with the environment 3. Perception and ethnobiology: study explored the social perception of biological invasion 4. Scientometrics: statistically analysed publications/studies on plant invasions
Approach	Research environment	1. *In vitro* 2. *In situ* 3. *In silico* (i.e. an experiment performed on computer)
Impact	The study addressed the (negative) impact caused by the species' invasion	0. Did not address impact 1. Ecological (ecosystem damage) 2. Economic (financial loss) 3. Social
Control	The study tested or proposed some method for managing the invasion	1. Yes 2. No

and none in 2007 (Fig. 1A). In total, 36 publications (≈ 10% of the sample) were retrieved that provided some definition of IAS. Amongst these, four publications provided no references for the definition of IAS and 45.7% of those published in 2021 provided a definition (Fig. 1B). Regarding the category of the study, 342 publications (81.4% of the total) addressed the ecology of IAS, 42 (10.5%) provided species lists, 21 (5.2%) consisted of scientometric studies and 11 (2.7%) included studies on perception and ethnobiology. Between 2002 and 2005, only publications on the ecology of IAS were found. The first species list was recorded in 2006, the first scientometric approach in 2008 and the first study on perception in 2012 (Fig. 1C). Overall, 235 (59.2%) of the studies relied on *in situ* methodologies, 115 (28.8%) *in vitro* and 21 (10.3%) *in silico*, with an additional nine studies using both *in vitro* and *in situ* methodologies and with seven (1.8%) publications providing no information about the methodology. The first publication that used an *in silico* methodology was in 2008 (Fig. 1D). In total, 95 (23.6%) publications reported some negative influence caused by plant invasion. Of these, 90 (94.7%) addressed ecological impact, whereas economic impact, ecological and economic impact and ecological and social impact were reported by 4.2%, 1.0% and 1.0% of the publications, respectively (note that no studies addressed only social impact). The first record of a publication that addressed economic impact was from 2017 and of one that addressed social impact from 2018 (Fig. 1E). Of the 398 publications analysed, only 69 mentioned measures for the management of IAS, representing 17.3% of the studies considered (Fig. 1F).

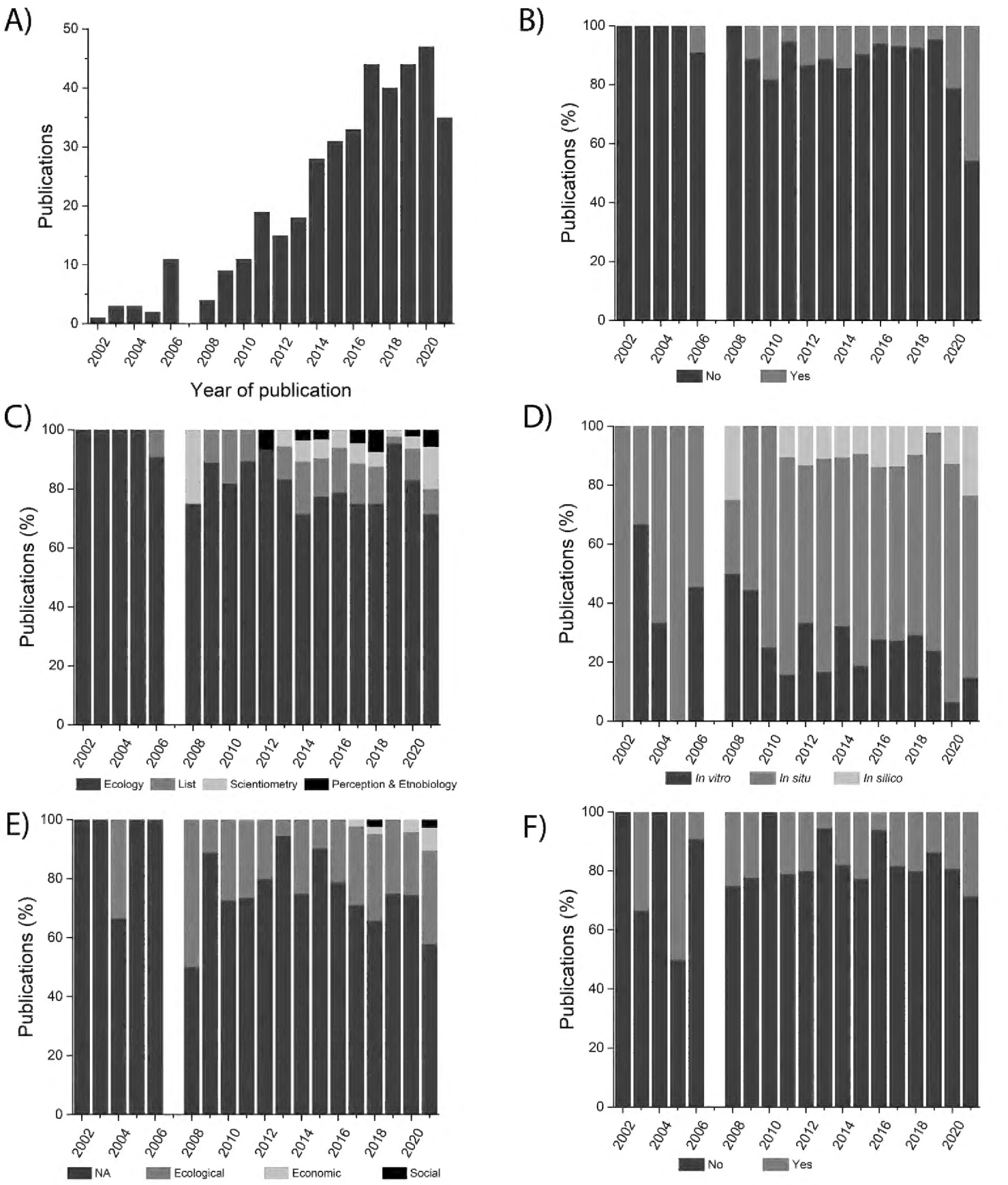

Figure 1. Charts showing the trend in publications (academic articles) on invasive alien species (IAS) of plants in Brazil from 2002 to 2021 as retrieved from the Web of Science, Scopus and SciELO databases (see Table 2) **A** number of publications retrieved per year **B** proportion of publications providing a definition of IAS **C** proportion of categories of publications **D** proportion of methodological approaches (i.e. study environment) **E** proportion of publications that addressed some type of impact **F** proportion of publications presenting measures of management.

Discussion

The methodology adopted in the present study for identifying academic articles by evaluating both title and abstract and, in case of doubt, using the body of the text, has

been used in recent environmental scientometric studies (Moral-Muñoz et al. 2020; Pinto et al. 2020; Fonseca et al. 2021). Considering the time range and methodology used, the number of academic documents analysed in the present study has provided a representative sample in this field of research compared to previous similar studies. Thus, Dias et al. (2013) reviewed all articles published in scientific journals (databases not specified) that used the terms "invasive exotic species" or "biological invasion" in "Brazil" before 2012, obtaining 124 publications. Frehse et al. (2016) used WoS to identify studies on biological invasions in Brazil published until 2014, resulting in 354 publications. Romero (2020) searched for publications on plant IAS in Latin American countries between 1945 and 2019, obtaining 373 publications for Brazil.

In the last 20 years, the number of academic articles that have addressed IAS of plants has grown substantially, highlighting the importance of the topic in plant conservation (Paclibar and Tadiosa 2019). The present results indicate that research in Brazil has focused on basic aspects of invasions (> 81% of the publications surveyed), such as biological knowledge of the invasive plants and their ecological relationships with the invaded area. Thus, despite growing knowledge on the number of alien plant species in Brazil (Frehse et al. 2016), there is a lack of research on their establishment, dispersion or impacts (Pinto et al. 2020). Consequently, *in situ* approaches are used because this method provides more accurate perspectives on the behaviour of IAS of plants (Barbet-Massin et al. 2018).

The way in which plant invasions have been studied has also changed. In the last six years, a slight increase in the number of *in silico* studies has been observed. This approach has been used in studies that focus on scientometrics and invasive species. However, the small number of surveys and scientometric studies associated with the limited use of the *in silico* approach indicates a lack of studies on plant invasion management (Zenni et al. 2016) and on the investigation of tropical environments. These approaches are critical for supporting conservation planning in tropical areas (Barbosa et al. 2012). Furthermore, there are gaps in the prediction of the number of alien species (Seebens et al. 2020). Given the need to understand the state of the art of the science of biological invasions and to advance research on the management of IAS, an increase is predicted in the number of publications using the *in silico* approach in the coming years.

Despite explaining biological invasion through invasion attributes (i.e. phenotypic plasticity, allelopathic compounds, invasiveness and invasibility), almost 87% of Brazilian studies presented no clear definition of biological invasion. However, these observations are not restricted to articles from Brazil. Indeed, Pereyra (2016) stated that, between 2011 and 2012, only 13% of academic articles provided a definition of 'invasive species' in the main international scientific journals. Moreover, the lack of consensus on terminology creates doubts regarding the meaning of biological invasion, including when to consider a given situation as an invasion (Moro et al. 2012; Simberloff 2012). Often, terms such as 'invasive' and 'invader', which may sound more attractive than 'exotic' or 'introduced', are used out of correct context (Pereyra 2016). This makes accurate communication of biological invasions difficult, produces mixed results and provides scope for the use of the term 'invader' without a definition or ecological verification. Furthermore, owing to the lack of consensus about terminology within the scientific community and the ecological complexity surrounding biological invasions, society is less aware of this global threat when

compared to most other threats that cause biodiversity loss (i.e. agricultural expansion, climate change, hunting: Courchamp et al. 2017). For this reason, it is recommended that future studies should focus on providing a definition of biological invasion in a clear and objective way, i.e. based on scientifically validated literature and/or ecological evidence.

In the present study, only 23.8% of the publications retrieved addressed an impact, which demonstrates a lack of Brazilian studies exploring the consequences of biological invasion. Most studies addressing impacts from IAS in Brazil have focused on losses in agricultural production (Adelino et al. 2021). The lack of relevant data on the impacts of IAS in natural areas creates barriers to effective management (Diagne et al. 2020) and this is especially important given that 'demonstrating' rather than 'assuming' invasiveness/impact is a crucial aspect in the risk analysis of IAS (Vilizzi et al. 2022).

Of the publications that addressed impact(s), only 5% (1% of the total) reported economic impacts caused by invasive species. Recently, Adelino et al. (2021) reported losses of USD 105.53 billion attributed to the biological invasion by only 16 species in Brazil. However, if the current number of invasive species in the country is considered, then the real economic loss due to such invasions might be much higher than published figures. One of the consequences of this lack of studies on the economic impacts of invasions includes low investment in the management of IAS (Zenni et al. 2021). Only 17.3% of the studies retrieved suggested control alternatives for IAS. Hence, despite the increase in the number of studies on the biological and ecological aspects of IAS of plants in Brazil, several gaps remain in the study of the management of these invasions. Lack of awareness about the importance of this topic, difficulties associated with the planning, coordination and organisation of competent public bodies and an inherent lack of research aimed at the control of IAS in developing countries (Weidlich et al. 2020) are major challenges for the management of IAS of plants in Brazil. Therefore, future research in this country should also consider the impacts of IAS of plants with a view to controlling them. Finally, *in silico* studies or studies evaluating IAS metadata in Brazil would allow the identification of trends or behaviour of invasive species in tropical environments and the identification of those with greater impact.

In conclusion, despite the growing body of scientific literature regarding IAS of plants in Brazil, the lack of data on the impact of IAS and the lack of consensus on the definition of invasion limit current understanding of the topic. This has direct implications for the recognition of its importance in natural areas and indirect implications on the understanding of the consequences of biological invasions for society. Consequently, for successful management actions against IAS, this lack of consensus represents an even worse impediment. Additionally, only few scientific documents have addressed or mentioned IAS control or management. For this reason, scientometric studies should be conducted to understand more comprehensively IAS in Brazil so as to provide guidelines for future research. Overall, it is recommended that future studies on IAS of plants should: (i) clarify and establish a consensus on the definition of biological invasion; (ii) understand the negative effects of such invasions using diverse methodologies (i.e. *in situ*, *in vitro* and *in silico* methods); and (iii) identify objective measures for the mitigation and control of the threat posed by biological invasions on biodiversity and ecosystem services.

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